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The Safety Impact of Additional Blue Lights of Rescue Vehicles

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Abstract

This work is a preliminary study on behalf of the Bavarian Red Cross (BRK). It examines if and to what effect an impact on traffic safety can be measured when BRK ambulance vehicles are equipped with additional blue lights on the front fender next to the front lights.
The high crash risk particular during emergency drives has been reported in numerous studies. The BRK endeavors to decrease the crash frequency of their ambulance vehicles by improving their visibility especially at intersections and narrow gateways. Therefore, additional side flash lights have been proposed. The purpose of this study is to evaluate the effectiveness of these flash lights. In this context, emergency drives conducted with equipped and unequipped ambulance vehicles were compared. More precisely, the exit of a BRK station and the surrounding road segment was observed for 14 days by a video camera, which enables computer-vision aided analysis of the traffic. Within this time frame, 38 traffic situations of unequipped and 13 situations of equipped ambulance vehicles could be observed. The trajectories of interacting road users in these situations were analyzed. The use of Surrogate Safety measures appeared to be not practicable to obtain statistical significant results due to few interacting trajectories and no critical situations. Instead, indicators for the adaption of road users to ambulance cars leaving the station were used, like deceleration, position and time of braking and time of reaching walking speed.
The indicators showed, that road users entered the observation area slower encountering equipped ambulance vehicles—probably due to prior braking —than was measured at emergency drives without additional flash lights. Furthermore, road users on average were breaking 3.5 m earlier, less intensely and reached walking speed 4 m earlier when ambulance vehicles were equipped with additional flash lights.

Keywords

Ambulance Vehicles, Traffic Safety, Risk, additional flash lights (3 – 5 keywords)

Figure 1: Additional side mounted blue lights at a MICU (source: BRK)

1. Motivation

The Bavarian Red Cross (BRK) aims to increase the safety of ambulance vehicles, so called Mobile Intensive Care Units (MICU) in road traffic. One possible measure in this context is to improve the visibility of MICU through additional side blue lights. In Figure 1 an MICU is shown with additional side blue lights.
The aim of the study was to conduct efficacy studies of additional side blue lights in road traffic based on empirical data.

2. Approach

In a first phase of investigation (phase 0 and subject matter of this report), the goal is to provide a principal feasibility of a proof with comparatively little effort The effectiveness of the additional side blue lights is therefore estimated on the basis of comparative examinations in which two vehicle classes participate: with and without additional blue lights. By means of image processing methods it is examined, how often critical situations occur in flowing traffic, when an MICU enters the moving traffic. Critical situations can generally be assessed using criticality measures such as TTC (time to collision), PET (near miss), DRAC (necessary deceleration to prevent an accident) and location of braking points, as well as the maximum deceleration.
To do so, digital videos are recorded from traffic events and evaluated using digital image processing methods. The goal is to determine the distribution of the location and frequency of critical situations .Based on these distributions safety promoting measures and installations can be evaluated and compared.

Figure 2: Location BRK Kreisverband Schweinfurt, rescue station Schweinfurt, Niederwerrner Str. 13, looking west (Friedrich-Ebert-Straße)

The digital videos were recorded with such a low resolution that no personally identifiable information such as registration plates or faces of road users were recognizable. After the evaluation, the video data were deleted, with the exception of short sequences, which are necessary for the documentation of selected critical situations, in order to draw possibly conclusions about the effectiveness of the additional blue lights.
First of all, test images were requested by various rescue teams in order to be able to assess the suitability of the site for a comparative examination. Finally, the rescue station Schweinfurt in Niederwerrner Straße 13 (see Figure 2) was selected. In a first step (phase 0), video recordings of the traffic situation in front of the BRK rescue station in Schweinfurt were created in order to assess the feasibility of the approach.
Afterwards, an on-site appointment took place in the rescue station Schweinfurt, where test pictures were taken from different office windows in order to find the suitable perspective (see example at Figure 2). Finally, a perspective was selected that is characterized as follows (Figure 3):

- Unobstructed view of the traffic approaching the exit of the rescue station.
- The vehicles on Niederwerrner Straße pass the exit of the rescue station
- Outward MICU cross the carriageway from the right
- Outward MICU emerge from behind a house, i.e. they are completely or partially hidden before they hit the road
- The road users can be detected within a range of 35m from the potential point of conflict and their movement lines (trajectories) recorded in order to detect the possible interaction between MICU and the road users

Then, a commercial camera (GoPro Hero II) was placed in the window of one of the ambulance offices (Figure 3). This recorded a digital video over a period of 4-5 hours. Afterwards it needed to be recharged. In total 14 days of videos were recorded.
The inspection of the recorded material showed that within the 14 days a total of 51 missions with siren and blue light had been recorded. Of these, 13 scenes were containing vehicles with side blue lights in use and 38 scenes without side blue lights. A closer examination of the scenes revealed the following:

- Often there is no vehicle interaction between MICU and other road users because there is no traffic. Those were discarded.
- Several recorded operations from East and West were carried out by other rescue services, like police and fire brigade. These were discarded as well.
- Construction work or marking work on the road took place on several days.
- Operation was started in different traffic conditions. The spectrum ranges from free flow traffic to traffic jams.
- In a single scene, two MICU appeared immediately one after the other: one with and one without side blue lights.
- In two scenes the MICU approached from the west (see Figure 3 on the right),
- and in all other scenes the MICU left the station coming from the south via the exit (Figure 3).

Figure 3: Detection area and interacting vehicles (East view). Left: Interaction with MICU coming from the south, Right: Interaction with MICU when leaving the rescue station from the west

3. Implementation

The study was carried out with software tools for the detection and tracking of road users in video sequences, which were developed especially for this purpose at the German Aerospace Center. The software is capable of recognizing vehicles in pre-defined detection areas (virtual loops) and of tracking them through the area of sight. The application of this software makes it necessary to conduct the following steps:

- Provide video scenes
- Determine the parameters of the exterior and interior orientation of the camera for the various 14 days of use. This model of optical imaging allows a projection of the action in the two-dimensional camera image onto the real 3-D world; thus speeds etc. become measurable
- Provide training data for the virtual loops
- Automatic processing of video sections, generation of trajectories
- Evaluate the trajectory data and collect of the relevant parameters described above

3.1. Determination of the exterior orientation parameters

At each of the 14 different shooting days, the camera was mounted in the same position, but there were slight variations in orientation. These arise when the camera is re-inserted manually into the holder, which leads to minimal changes in the orientation of the camera. These minimal changes result in errors of several meters when projecting image coordinates into world (UTM) coordinates. The projection error increases with distance from the camera. As stated before, the projection is necessary in order to derive trajectories in world coordinates and measuring position and kinematics in common metrics units (m/s etc).
These errors were avoided by re-calibrating the exterior orientation parameters for each scene. In such a calibration, prominent points in the camera image are marked pixel-accurately and their correspondence is indicated in the map. Software developed at DLR then calculates the imaging parameters (see Figure 4).

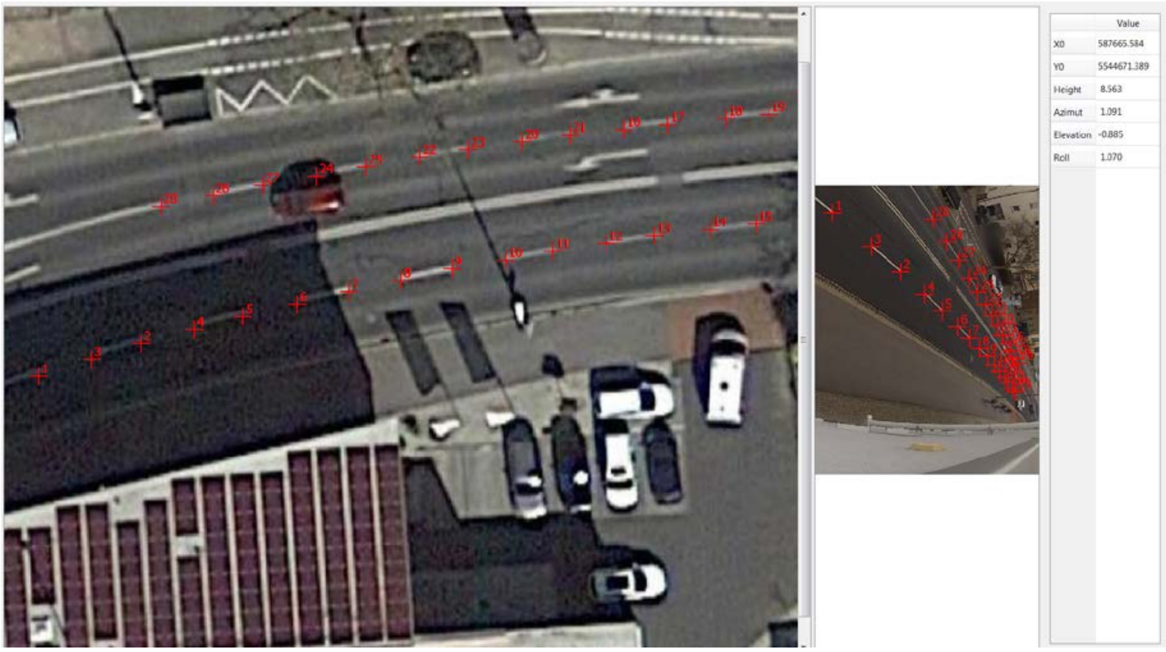

Figure 4: Corresponding points in map and camera image

As a result, it was found that the accuracy of projecting the camera image onto the map image was better than 10 cm for the entire area of interest—from the entrance of the road users to the exit of the rescue station. The calibration is considered suitable for carrying out the investigation (for more detailed consideration of the influence of measurement accuracy on the determination of critical situations in traffic see Leich et al. (2016).

3.2. Providing Training Data for Virtual Loops

During the automatic processing of the video data, the vehicles pass previously defined image areas (virtual loops). A pattern recognition algorithm determines how similar the image content is to the image of classified reference vehicles and outputs a corresponding similarity value. The Histogram of Oriented Gradients (HoG) combined with a support vector machine (SVM) was used as recognition algorithm as proposed by Dalal & Triggs (2005).

In order to achieve optimum optical loop performance, training data was manually created over the entire 14-day period under various weather conditions (see Figure 5). The study generated approximately 3000 training data examples (50% vehicles and 50% background) for three virtual loops (right lane, lane changer and left lane) and finally estimated the detection quality based on samples from the various randomly selected scenes. Within the 14 days, out of 526 vehicles 524 were correctly recognized (true positive) having 5 errors (false positives). The pattern recognition algorithm and the number of training data were therefore considered suitable for carrying out the examination.

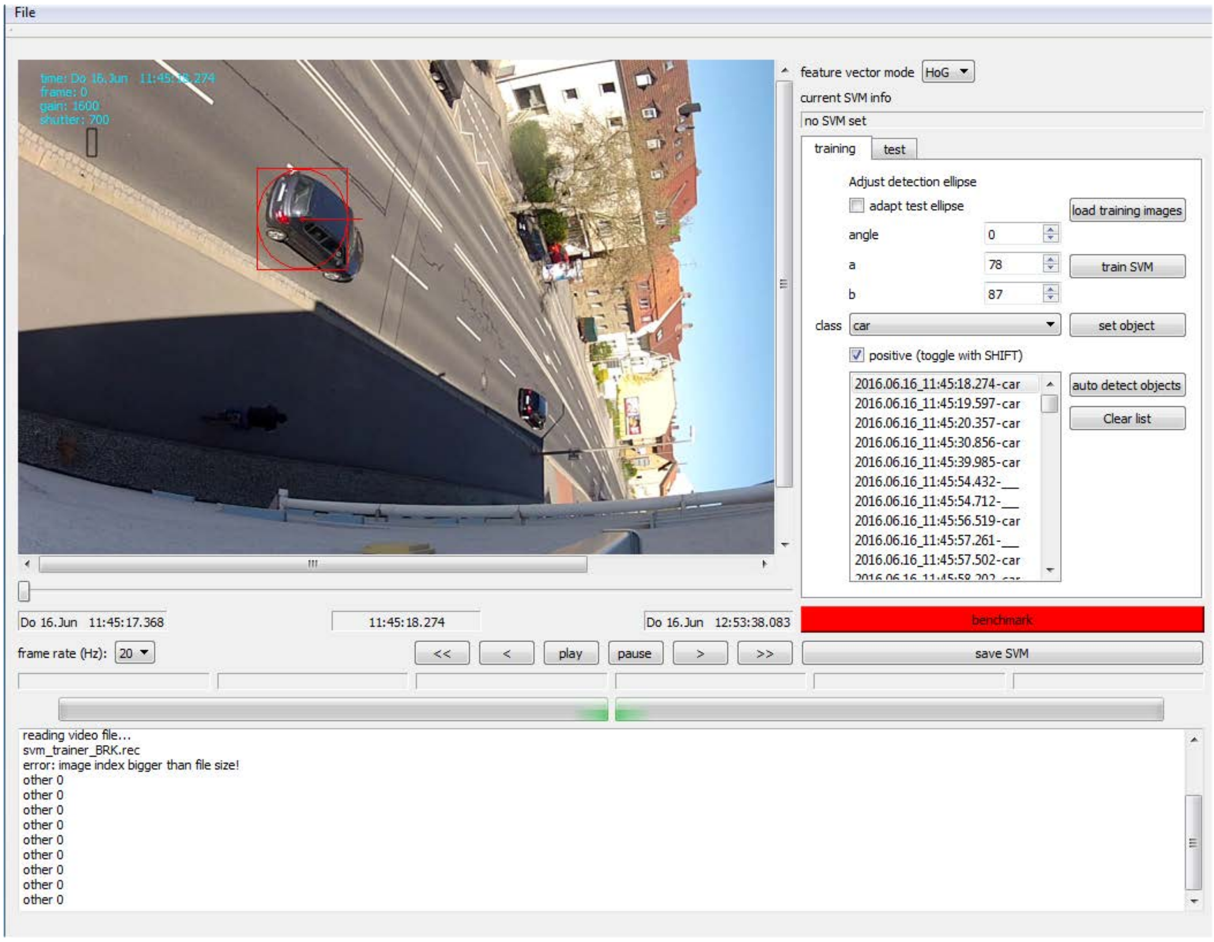

Figure 5: User interface for image processing methods training

3.3. Image Processing and Calculation of Trajectory

In the following the algorithm for object detection and vehicle tracking is briefly explained: The whole process of detecting a vehicle and tracking it, resulting in a trajectory, is automated. If a vehicle passes through the virtual loops (red ellipses), the calculated similarity score rise, as shown in Figure 6. There, only one MICU passes through the loops *svm_2* (left lane) and *svm_0* (lane changer). The software generates the object candidate 7 and tracks it through the scene using an optical flow algorithm (see Leich et al. 2015). Then a red car passes through the virtual loops *svm_1* (right lane) and *svm_0* (lane changer). The loops *svm_0* and *svm_1* show increased similarity scores. The non-maximum suppression algorithm selects the object candidate 11 and tracks it. The projection onto the map (Figure 7) shows the objects 2 and 11 in 3D (or 2.5D) coordinates.

For all trajectories, space-time images, speed-time diagrams, and speed-location diagrams were generated. The diagrams were used to determine the following parameters:

- Entry speed into the detection area, directly readable in speed-time diagram
- Maximum deceleration, calculated by selecting two points in time in the velocity-time diagram
- Auxiliary variable: Time of braking (braking acceleration exceeds 1 m/s^2). This time was read from the acceleration time diagram.
- Location of the braking determined in the space-time image from the time of braking
- Location where the walking speed of 1.5 m/s was reached. Readable in the speed-space diagram

Figure 6: Three virtual loops and time plot of the similarity score (SVM_1: right loop, SVM_0: middle loop, SVM_2: left loop)

Figure 7: Object locations after perspective projection

3.4. Evaluation of Trajectory Data

For the relevant indicators, distributions and averages were determined. See Figure 7 through Figure 10, Table 2 and Table 3. All calculated indicators show a tendency towards more favorable values in terms of criticality when the additional flash light is in use.

- The low entry speeds indicate that braking is often already done before entering the observation area. The average entry speed is 8.16 m/s (29.4 km/h) with flash light vs. 9.22 m/s (33.2 km/h) without flash light, or 12% lower.
  The average of the maximum acceleration of the road users is 2.03 m/s^2 with side flash light than without side flash light (2.18 m/s^2).
- The distribution of brake application points over the path shows that vehicles start braking on average 3.5 m (8.1 m vs. 4.6 m) earlier when the flash light is active. A vehicle approaching 50 km/h slows down an average of 0.25 s earlier.
- The distribution of the brake application points (see Figure 9) shows that almost two-thirds (64%) of the brake application points are between 0 and 7 m when no side-marker lamp is active. The top of the histogram is in the interval 4 m - 5 m. With side flash light the top of the histogram is in the interval 0 m -1 m and 7 out of 11 (64%) vehicles have already started to brake after 4 m . This suggests that more road users start to brake earlier when the side flash light is active.
- When the side flash light is active, the vehicles reach walking speed after about 12 m on average, while this is the case after almost 16 m when no side flash light is active. The mean coincides with the top of the histogram (see Figure 10)

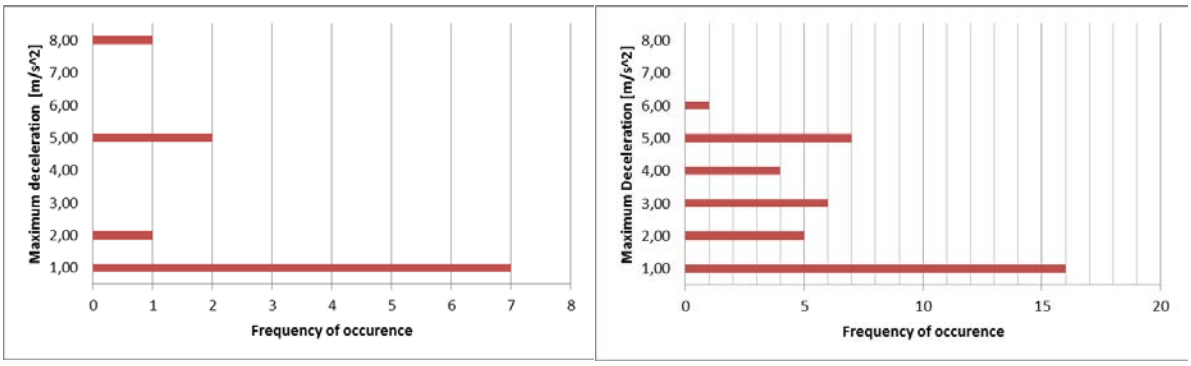

Figure 8: Histograms of the maximum deceleration in the detection area. Left with, right without flashlight

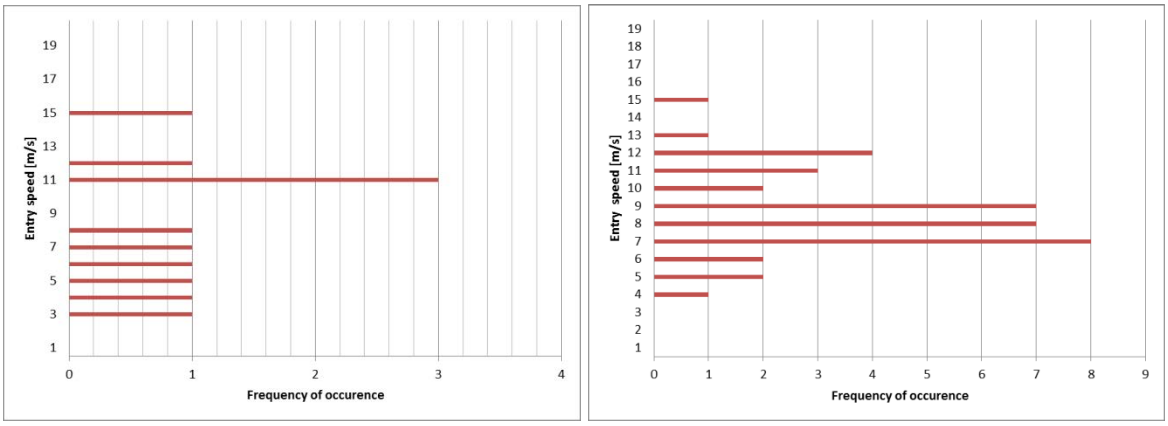

Figure 9: Histograms of the entry speeds into the detection area. Left with, right without flashlight

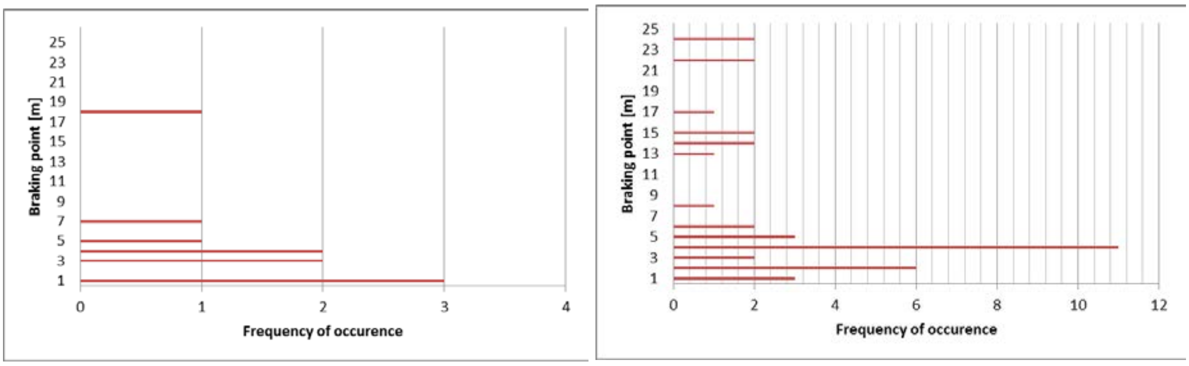

Figure 10: Histograms of braking points in the detection area. Left with, right without flashlight

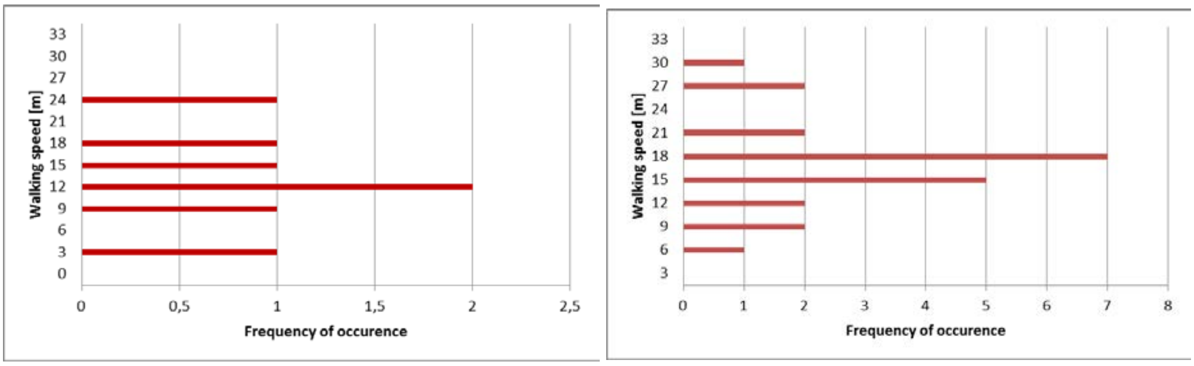

Figure 11: Histograms of the locations where the walking speed is reached in the detection area. Left with, right without flashlight

For significance assessment of the results the Kolmogorow-Smirnow-Test (KS-Test) was conducted. This statistical test makes it possible to accept or reject a null hypothesis. The null hypothesis in this case is "There is no significant difference between the distribution of the entry speeds / maximum deceleration rates / braking points / points when the walking speed is reached with and without the use of additional flash lights". The null hypothesis is to be rejected if a maximum deviation (difference) D between the empirical frequency distributions exceeds a minimum value $D_{critical}$.
Table 1 shows that the result is not significant for any of the parameters collected. The highest level is the significance level with only 9.5% error probability for the entry speeds, the lowest with 32% error probability for the distribution of the maximum deceleration. Illustratively, one can expect that on average of three comparable studies only one comes to the conclusion that no influence of the side flash light is detectable, while two confirm the influence. Conform to Bortz (2013), the rejection of the null hypothesis requires a significance level of 1% (99 out of 100 studies would give the same result).

Table 1. Significance of the results according to KS-Test. Left column: distance of empirical frequency distributions, middle: critical distance, right: probability of error

	D	$D_{critical}$	P
Entry speed	0,128	0,556	9,5%
Maximum deceleration	0,223	0,556	32%
Braking point	0,301	0,603	26%
Location of reaching walking speed	0,35	0,704	25%

3.5. Findings for Study Planning

With the help of the KS-Test, it is possible to estimate how large the sample would have to be in order to achieve a reliable, statistically significant result. Here, the following assumptions are made:

a) a measurement takes place over a longer period of time
b) again, trajectories are recorded by road users interacting with MICU
c) again, there are about four times more trajectories of duty rides without flash light than of service rides with flash light ($4n_{flash} = n_{noflash}$)
d) the distance D between the empirical distributions always remains at the level measured in the pre-study

Then the number n_{flash} of necessary trajectories can be calculated as follows:

$$4n_{flash} = n_{noflash}$$

$$D_{critical} = \lambda_\alpha \sqrt{\frac{n_{flash} + 4n_{flash}}{4n_{flash} n_{flash}}} = \lambda_\alpha \sqrt{\frac{5}{4n_{flash}}}$$

$$n_{flash} = \frac{5}{4}\left(\frac{\lambda_\alpha}{D_{critical}}\right)^2$$

The parameter λ_α is a constant of the KS-Test. For a significance level of 99%, λ_α is 1.63. The corresponding value

Table 1 summarizes the results of the calculations for the various parameters considered. It can be seen that the size of the sample would have to be increased by a factor of 20 in order to obtain a significant result at the entry speeds. This would mean that for 40 weeks (or less than a year) daily digital video would have to be recorded with a GoPro camera. For the other parameters, the estimated cost is 3 to 7 times the current 2 week recording time.
These estimates will only be confirmed if assumption d) is true. However, there is reason to believe that the distance between the distributions goes down when the number of data samples goes up. This is because

sampling errors tend to be smaller if the empirical distributions are sampled on a finer grid. It is therefore advisable to provide a reserve.
Therefore, we assume that with a permanently installed camera in 24-hour operation, a collection time of 3-4 months should be sufficient for collecting enough data for significant results.

Table 2. Numbers of necessary trajectories for statistically significant results

	D	n_{flash}
Entry speed	0,128	202
Maximum deceleration	0,223	67
Braking point	0,301	37
Location of reaching walking speed	0,35	27

Table 3: List of road users interacting with MICU with side flash light

Data Base ID	v_0 [m/s]	Max. Deceleration [m/s^2]	Braking point [m]	Walking speed [m]
70	6	1,68	2,5	9,5
72	-	-	-	-
73	5	0,29	1	8,5
74	2,5	0,50	1	2,5
75	10,7	0,60		
76	10,5	4,67	18	23
77	11,7	5,00	3	14,5
79	3,7	0,63	1	9,5
82	10,5	0,75	5	
83	7,8	0,50	4	
91	14,4	7,20	7	18
92	7	0,50	3,5	
Average	8,16	2,03	4,60	12,21

Note: The vehicle with the ID 72 database (ID 7 in Figure 6) is not scored because it is an MICU

Table 4: List of road users interacting with MICU without side flash light

Data Base ID	v_0 [m/s]	Max. Decelaration [m/s^2]	Breaking Point [m]	Walking speed [m]
3	9	4,40	4	9,3
4	9,7	0,50	5	
6	8,8	1,40	15	29
7	8,2	4,00	13,5	17
8	7,5	2,22	8,5	8,5
10	9,8	3,60	5	
11	4,5	2,00	2	3,5
13	9	0,20	23	
14	10,9	0,20	5,5	17
15	11,4	4,40	5	18
17	9,2	3,00	4,5	14
20	9,6	4,40	4,5	12,5
21	13,4	6,00	7	17
22	7,4	2,61	3,5	9
24	9,6	0,91	5	
25	9	1,00	2,5	
27	7,8	0,20	5	
28	7,2	0,20	2	
30	11,2	4,10	5,5	17
32	11,2	4,20	5,5	14,5
33	5,6	1,00	3	12
34	9,8	0,50	5	
35	8,5	1,00	24,5	
36	7,2	0,70	16	26
37	7,6	1,70	15	20
39	15,2	0,50	7	
42	12,6	2,60	23	
44	8,5	3,00	5	
45	12,4	4,20	5	18
46	10,8	0,40	5	
49	12,4	0,50	3	
50	6,2	1,20	4	
54	5,2	0,10	2,5	
57	7,2	1,00	2	14,5
60	12,4	4,70	15,5	18
62	10	4,00	25	27
63	9	4,00	18	21
64	7	2,00	3	14,5
66	7,4	2,20	3	9,5
Mean	9,22	2,18	8,10	15,95

4. Conclusions

All the indicators strongly suggest that there is a safety benefit when using the additional side flash light. The vehicles brake on average 3.5 m earlier and less strongly and reach 4 m earlier walking speed. We conclude from this, that vehicles have earlier perception of the ambulance vehicle. Given an average local speed of 50 km/h it can be assumed that the reaction time on the emergency vehicle is improved with a special signal of 0.2 - 0.3 seconds. In the presence of the flash light, the vehicles drive on average slower in the detection area because they presumably brake before.

Reaching walking speed by an average of 4 m earlier can, in the case of an emergency, be decisive in determining whether or not an accident occurs involving personal injury and material damage. As a result of this preliminary study, it is recommended to perform a complete study (phase 1), with a statistically significant underpinning of the result. It is very likely to be expected that robust test results and sufficient arguments for type approval of the additional side flash lights can be obtained.

The methods used are considered suitable for determining the ascertained parameters. In addition, it could be determined by visual inspection of the videos during the evaluation that the detection and tracking of road users succeeds sufficiently well.

Due to the fact that true interactions occurred only in comparatively few of the recorded scenes, it is possible that the result of this preliminary study is falsified by the influence of randomness; the safety gain could not be proven significantly due to the insufficient database. This means that another study over a similarly short period of time may yield different and even opposite results. For example, the greatest deceleration rate was registered with the ID 91 vehicle when an MICU with side flash light exited. A statistically reliable statement can only be made after evaluating data from a larger sample of interactions. This would have to be collected over a longer observation period of 3 - 4 months.

It is desirable to use a fixed camera so that no daily recalibration (determination of the external orientation) is required. It is also desirable to include and evaluate the coverage area in the west direction (Figure 2). This seems sensible due to the large number of vehicles that already had started braking before reaching the observed region of interest. Likewise, an automated detection of the acoustic signaling of the MICU is desirable.

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References

Leich, A., Kendziorra, A., Saul, H., & Hoffmann, R. (2016). Calculation of Error Rates for Detection of Critical Situations in Road Traffic. In *95th TRB Annual Meeting–Compendium of Papers (Vol. 95).* Transportation Research Board.

Dalal, N. & Triggs, B. (2005) Histograms of oriented gradients for human detection, *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)*, San Diego, CA, USA, 2005, pp. 886-893 vol. 1.

Leich, A., Junghans, M., Kozempel, K., & Saul, H., Road user tracker based on robust regression with GNC and preconditioning. (2015) In *SPIE/IS&T Electronic Imaging* (pp. 940702-940702). International Society for Optics and Photonics.

Kolmogorow-Smirnow-Test https://en.wikipedia.org/wiki/Kolmogorov-Smirnov_test

Bortz, Jürgen: Lehrbuch der Statistik: Für Sozialwissenschaftler. Springer Verlag 2013